The Schroeder Frequency of Furnished and Unfurnished Spaces

Seyed Mostafa KHEZRI
Department of Environmental Engineering, Graduate School of the Environment and Energy, Science and Research Branch, Islamic Azad University, Tehran, Iran
khezrim@gmail.com

Pedram Jafari SHALKOUHI
Department of Environmental Engineering, Graduate School of the Environment and Energy, Science and Research Branch, Islamic Azad University, Tehran, Iran
pedram121212@yahoo.com

Abstract: - This paper considers the situation in which an empty room is furnished. Hence, the Schroeder frequency of an empty room is compared with the Schroeder frequency of the same room when it is furnished. It is concluded that the Schroeder frequency of empty spaces is more accurate compared with the Schroeder frequency of furnished spaces.

Keywords: - Schroeder frequency, furnished and unfurnished spaces.

1. INTRODUCTION

In enclosed spaces the transition from individual resonances to many overlapping normal modes is called the Schroeder frequency which can be computed as follows:

\[ f_s = 2000 \sqrt{\frac{T}{V}} \]  \(\text{(1)}\)

where V is the room volume (m³) T is the Sabine reverberation time (sec) and \(f_s\) is the Schroeder frequency (Hz) [1].

The reverberation time formula proposed by Sabine is:

\[ RT = 0.161 \frac{V}{\alpha A} \]  \(\text{(2)}\)

where V is the room volume (m³), A is the surface area of the room (m²), \(\alpha\) is the average absorption coefficient of the surfaces and RT is the reverberation time (sec) [2].

The room behavior can be subdivided into regions based on the Schroeder frequency. Figure 1 indicates the type of behavior which can be expected from the SPL (sound pressure level) in a room plotted against frequency. It also shows the techniques which can be used in order to control the steady state room response. Because in small spaces the normal mode region can extend to several hundred Hertz, a statistical model can only be applied at high frequencies [3].

![Figure 1. The frequency response of a typical room [4]](image)

The Sabine equation is only valid for rooms with \(\alpha\) less than about 0.3 because it comes increasingly inaccurate when the absorptions are increased [5].

The total Sabine absorption in a room would be easy to get if all surfaces of the room were uniformly absorbing, but this condition rarely exists because floor, walls, and ceiling may be covered with different materials and as well as doors and windows [6].

Effects such as interference or diffraction and behavior of sound waves which can be affected by the room shape, existence of standing waves and normal modes of vibration are not embodied in the Sabine equation [7].

Critical distance (also called reverberation distance, reverberation radius, diffuse field distance) is defined as a point in a room where the direct sound field and the reverberant sound field are equal [8].
The critical distance can be calculated as follows:

\[ D_c = 0.141 \sqrt{Q.S.\alpha} \] (meters or feet) (3)

where \( D_c \) is the critical distance, \( Q \) is the directivity factor of the sound source, \( S \) is the surface area in the space, and \( \alpha \) is the average absorption coefficient in the space [8].

Also, critical distance can be calculated as:

\[ D_c = 0.03 \frac{V}{T} \] (4)

where \( D_c \) is the critical distance (ft), \( V \) is the room volume (ft\(^3\)) and \( T \) is the reverberation time (sec) [9].

The direct sound follows the inverse square law it means that at twice the critical distance the direct sound will be 6dB below the reverberant sound. Beyond the critical distance where the reverberant field dominates, the sound levels intensity off to a statistically constant level. The critical distance can be increased by using the directional loudspeaker [10]. The critical distance is important concerning speech intelligibility [9].

In real halls, the reverberant sound field level is not constant, but gradually falls with increasing distance, as energy is dissipated due to factors including the room boundaries, audience and air [11].

Schroeder [12] indicated that the Schroeder frequency when expressed as a crossover wavelength equals the critical distance with a numerical constant.

In a classroom of average size with a commonly reported level of reverberation, the reverberation distance would be approximately 3m to 4m from the teacher [13].

Toole [11] reported that critical distance is not a useful concept in small spaces. Also, Toole concluded that a new measure with regard to the relative strengths of direct and early reflected sounds is needed.

Shalkouhi [14] calculated the Schroeder frequencies of classrooms studied by Knecht et al [15]. The calculated Schroeder frequencies ranged from 67Hz to 141Hz. Shalkouhi concluded that the Schroeder frequency with regard to reverberation time measurement in classrooms must be considered.

Toole [11] found that a method of easily identifying and computing the Schroeder frequency in small spaces is needed.

Figure 2 indicates the Schroeder frequency for different room volumes and reverberation times. For room volumes less than 60m\(^3\) with the reverberation times between 0.5 sec and 1 sec, the lowest Schroeder frequency will be at the 200 Hz one third octave band, and often at higher frequency bands [16].

![Figure 2](image-url)
Multiplying both sides of the equation as follows:

\[ V\alpha_1 A_1 + V\alpha_2 A_2 > V\alpha_1 A_1 \]  

(9)

Simplifying the equation as follows:

\[ \alpha_2 A_2 > 0 \]  

(10)

**3. DISCUSSION**

Based on Eq. (7) it can be stated that if \( \alpha_2 > \alpha_1 \) or \( \alpha_2 < \alpha_1 \) or \( \alpha_2 = \alpha_1 \) then the reverberation time of an empty room will be greater than the reverberation time of the open plan office (see figure 3).

![Figure 3. Reverberation time with regard to room geometry](image)

Moreover, if \( \alpha_2 < \alpha_1 \) then the reverberation time will decrease (figure 3) while according to the Sabine equation, reverberation time is a function of the room volume and absorptions it means that if absorptions are increased, the reverberation time will decrease.

![Figure 4. The Schroeder frequency with regard to room geometry](image)

Therefore, it can be stated that when an empty room is changed to open plan office it is analogue to decreasing the room volume in other words, additional partitions (if \( \alpha_2 < \alpha_1 \)) in a room shorten the rout for the transmission of sound energy hence the sound energy is attenuated faster compared with the same room with no partitions. Furthermore, according to the Schroeder frequency if a room volume is increased, the room will be more diffuse (figure 4).

Moreover, if an empty room is changed to open plan office, the reverberation time of the new space (open plan office) will decrease and the open plan office will be more diffuse based on the Schroeder frequency. But it must be noted that the reverberation time of the open plan office is only decreased due to the additional partitions (if \( \alpha_2 < \alpha_1 \)) which is analogue to decreasing the room volume. Therefore, if the room volume is decreased, the room will be less diffuse (figure 5). In contrast, if the room volume or the average absorption coefficient is increased, the room will be more diffuse.

![Figure 5. Comparison between the Schroeder frequency of an empty room with the Schroeder frequency of the same room when it is changed to open plan office](image)

In addition, when an empty room is furnished (see figures 6 and 7), despite the absorption coefficient of the furniture decreases reverberation time; this can shorten the rout for the transmission of sound energy which is analogue to decreasing the room volume. Hence, it can be stated that the reverberation time of furnished rooms is decreased.
due to both the absorptions and the act of shortening the route for the transmission of sound energy. Therefore, it is difficult to judge about the exact Schroeder frequency of furnished spaces.

**Figure 7.** Comparison between the Schroeder frequency of empty and furnished rooms of equal size (if $\alpha_{\text{furniture}} \leq \alpha_1$)

4. CONCLUSIONS

Therefore, it can be stated that the Schroeder frequency of empty spaces is more accurate compared with the Schroeder frequency of furnished spaces.

REFERENCES


